REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
08/28/2017	Poster	08/28/2017-08/31/2017

4. TITLE AND SUBTITLE
Building and Validating a Model of Human Blast Traumatic Brain Injury: A Hybrid Computational and Experimental Approach

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Maj Adam Willis

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
59th Clinical Research Division
1100 Willford Hall Loop, Bldg 4430
JBSA-Lackland, TX 78236-9908
210-292-7141

8. PERFORMING ORGANIZATION REPORT NUMBER
17336

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
59th Clinical Research Division
1100 Willford Hall Loop, Bldg 4430
JBSA-Lackland, TX 78236-9908
210-292-7141

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release. Distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Clarice Longoria
					19b. TELEPHONE NUMBER *(Include area code)* 210-292-7141

Approved for public release. Distribution is unlimited.

Building and Validating a Model of Human Blast Traumatic Brain Injury: A Hybrid Computational and Experimental Approach

Adam M. Willis, M.D., Ph.D., Maj, USAF[1,2], Candice Cooper, M.S.[3], Scott Miller, Ph.D.[3], Ricardo Mejia-Alvarez, Ph.D.[2], Michaelann Tartis, Ph.D.[4], Kelsea Welsh[4], Ann Wermer[4], Chad Hovey, Ph.D.[3], Faezeh Masoomi[2], Suhas Vidhate[2], Kyle Ferguson[5], Ian Fuller[5], Robert Morgan, Ph.D.[5], Daniel Perl, M.D.[5], Paul Taylor, Ph.D.[3]

[1]59th Medical Wing, [2]Michigan State University, [3]Sandia National Laboratories, [4]New Mexico Tech, [5]Los Alamos National Laboratories, [6]Uniformed Services University of Health Sciences

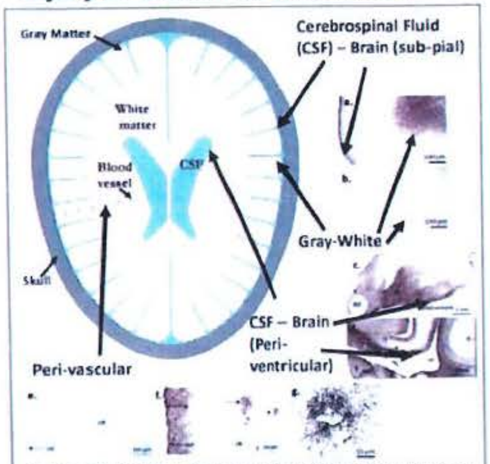
Introduction

Nearly 150,000 of the returning soldiers from Iraq and Afghanistan have suffered blast induced Traumatic Brain Injury (TBI), leaving the victims at risk for persistent neurologic/behavioral symptomatology, including headaches, sleep disorder, cognitive impairment and mood disturbance. Although defining what the injury of blast TBI is has been difficult and prone to confounders, looking to clinical data has helped differentiate this injury from other TBI. In theater experience from the physicians who treated blast victims identified some unique features of this injury; injury to the **blood vessels** at both large and small length scales manifesting with **brain swelling, subarachnoid hemorrhage or pseudoaneurysm and vasospasm** [1-4]. More recently, careful neuropathologic studies of victims of blast TBI demonstrated a unique pattern of astroglial scaring at multiple intracranial interfaces: **subpial, perivascular, periventricular, and gray-white junction** [5]. However, the mechanism(s) and threshold of these injuries have not been resolved mechanically, thus protective equipment cannot be optimized to reduce the injury. The purpose of this work is build a model which reproduces the **human intracranial injury** after blast exposure in order to isolate the mechanism(s) of injury.

Hypotheses

Observed patterns of blast traumatic brain injury can be explained by the focusing of blast stress waves that occur at the intracranial mechanical interfaces (CSF-brain, vessel brain, gray-white, etc).

Pathology of Blast Traumatic Brain Injury at Mechanical Interfaces [5]



Mechanical Properties of Cranial Contents [6]

	Density	Bulk Modulus	Shear Modulus
Skull	1.21 (g/cc)	4672 (MPa)	3270 MPa
White Matter	1.04	2371	41 kPa-G_0, 7.8 kPa-G_{∞}, B = 40 s^{-1}
Gray Matter	1.04	2371	34 kPa-G_0, 6.4 kPa-G_{∞}, B = 40 s^{-1}
CSF	.9998	1960	

Computational Methods

Material Models

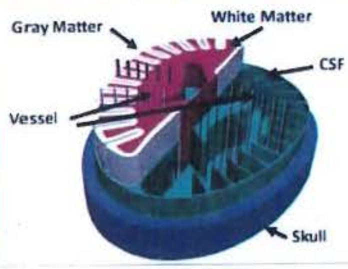
The material models utilized in CTH and Sierra are fit to material property data of human tissue published in the open literature for bone, white matter, gray matter, and cerebrospinal fluid. These material models have been previously employed and validated in modeling & simulation of blast and blunt impact of human models by Taylor et al. of Sandia National Laboratories [6-9].

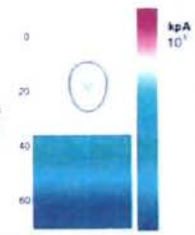
Computational integration – Eulerian (CTH)

CTH is an Eulerian finite volume computer simulation code that is capable of tracking 90+ materials simultaneously, simulating their interactions as they undergo blast loading. This code is is a validated shock physics simulation suite and has been used to study fluid-solid interactions that occur between blast waves and the test object model [10]. Blast wave was modeled as a slab of *energized* with overpressure of 260kPa.

Computational integration – Immersed Lagrangian (Sierra)

Sierra mechanics is the finite element simulation suite developed by Sandia National labs to predict behavior of complex structures under extreme loading. Blast loading is accomplished by passing pressures from CTH to Sierra/SM, where they are used as a boundary condition for the finite element simulation. This one way coupling is sufficient for large over pressure loadings. Future work will utilize a two way coupling for lower amplitude blast studies.



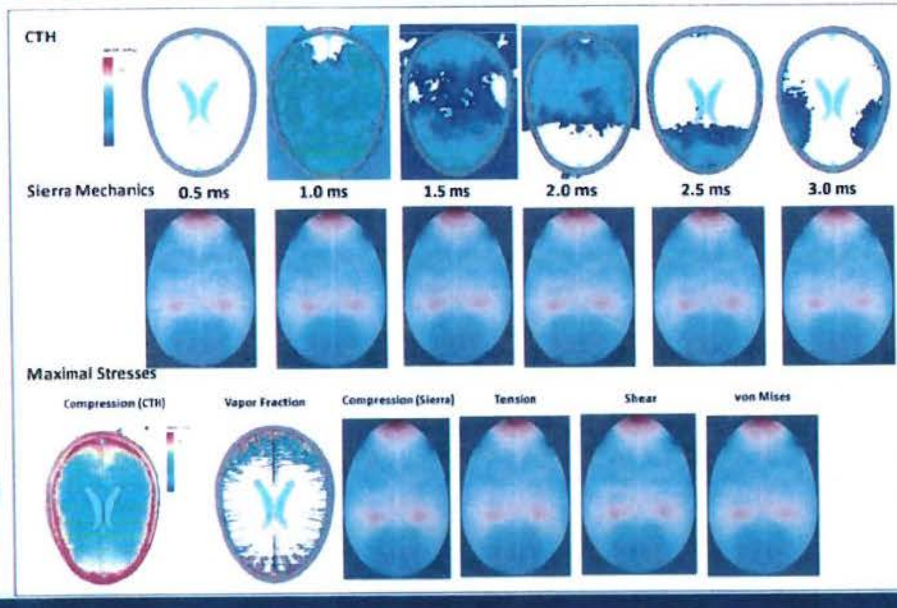


Computational Test Object

The test object employed within CTH is comprised of 5 explicit materials with a spatial resolution of 1 cubic millimeter. Specifically, these materials consist of the bone, white matter, gray matter, fluid (cerebrospinal fluid/blood), and blood vessel walls.

The Sierra/SM finite element mesh of the test object consists of 12 million linear Hexahedra, with a maximum element size of 0.5 cubic millimeters. The bone, white matter, gray matter, CSF, and vascular walls have been modeled with a conforming geometry.

Computational Results



Conclusions

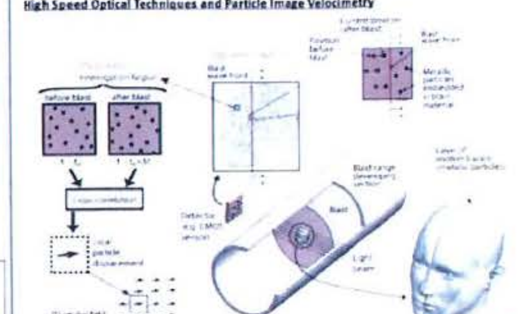
Computer simulations based upon material models matched to human tissue predict a predilection of cavitation and dilatational forces at the same interfaces found to have astroglial scaring in blast traumatic brain injury. Such findings require further experimental validation but may suggest cavitation and dilatation are mechanical forces important in causing brain tissue damage in blast traumatic brain injury.

Experimental Validation

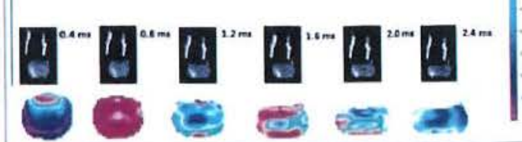
Brain Simulant - **See poster** MHSRS-17-1710: Materials Characterization of Cranial Simulants for Blast Induced Traumatic Brain Injury

Fabrication Techniques – **See poster** MHSRS-17-1718: Additive Manufacturing of Cranial Simulants for Blast Induced Traumatic Brain Injury

High Speed Optical Techniques and Particle Image Velocimetry



Dynamic measurement with ultra-high speed imaging while the blast wave is crossing the test object (above). Cavities in the test object have dimensions similar to those in the brain (zoomed-in view, upper left corner). Metallic particles embedded in the test object will trace strain as the detonation wave propagates (zoomed-in view at the edge of the detonation wave, above center). Particle Image Velocimetry (PIV) [11] will be used to generate 2D vector fields representing strain and strain rate (schematic of PIV process on the right). Below is the material velocity vectors of ballistics gel undergoing blunt trauma (hammer). Far right is velocity magnitude of vectors in m/s.



References

[illegible]